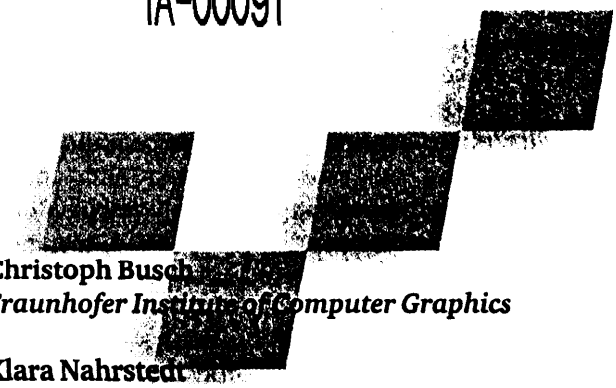

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# Image Security

Over the past decades, research in security has concentrated on the development of algorithms and protocols for encryption, authentication, and integrity of textual data or data with similar characteristics. Despite tremendous advances in security-specifically, the development of asymmetric cryptographic protocols and the inception of strong symmetric ciphers-plenty of security problems still afflict systems. For example, hackers exploiting weaknesses in other systems and the use of inadequate (too short) cipher keys produce frequent news headlines about broken security systems.

Despite the news headlines, such problems have been well explored and even solved in principle, therefore they aren't the primary focus of this special theme issue. Rather, the articles here cover the unsolved problems in image security, which relate fairly closely to computer graphics. The unsolved challenges arise from the increased availability and distribution of multimedia content over Internet services such as the World Wide Web and their implications for intellectual property protection and copyright issues.

A growing number of scientific groups in computer science and cryptography have confronted these challenges. Researchers are currently working on issues such as visual cryptography, mechanisms for the integrity of image material, digital signatures for multimedia data, and data hiding techniques. Data hiding, which has achieved the highest popularity, contemplates the crucial needs for protecting intellectual property rights on multimedia content like images, video, audio, and others. These needs demand robust solutions due to the explosion of publicly available multimedia information and the easiness with which this information can be distributed, copied, and modified. Watermarking technology meets these demands and provides a feasible approach to protect against-and prove-illegal copying and redistribution in the digital world.

This special theme issue presents four articles that discuss watermarking solutions for dedicated media types such as images, video, and geometric models. They range from an overview of fundamental watermarking concepts to the latest research results.

In "A Watermarking Framework for Copyright Protection of Digital images," George Voyatzis and Ioannia Pitas review fundamental watermarking concepts and develop a generic model for protecting the copyrights of digital products including a trusted registration authority.

"Digital Watermarking: From Concepts to Real-Time Video Applications" by Christoph Busch, Wolfgang Funk, and Stephen Wolthusen focuses on the specific demands and real-time requirements for video protection. Their solution, which is robust against strong MPEG-2 compression, is very important to the broadcasting and video stock industries.

Boon-Lock Yeo and Minerva Yeung address a new area of watermarking via 3D polygonal models with "Watermarking of 3D Objects for Verification." Their article takes an essential step into this untouched area. They provide mechanisms for embedding watermarks into geometric models as well as detection mechanisms for unauthorized modifications.

"Geometry-Based Watermarking of 3D Models" by Oliver Benedens presents fundamental progress in the same field. His contribution formulates a new definition for robustness of watermarks in correlation to 3D models, proposes a watermarking mechanism, and evaluates its robustness against a polygon simplification.

Finally, we would like to mention that we could not consider all the outstanding submissions received for this theme issue because of page limitations. Contributions were reviewed by up to six security experts from all over the world. We would like to thank all the reviewers, who provided constructive comments and strongly influenced the selection. Their choices allow us to provide a high-quality overview of the state-of-the-art in the field and describe exciting new developments and technologies. We hope you will enjoy reading the following pages. ■

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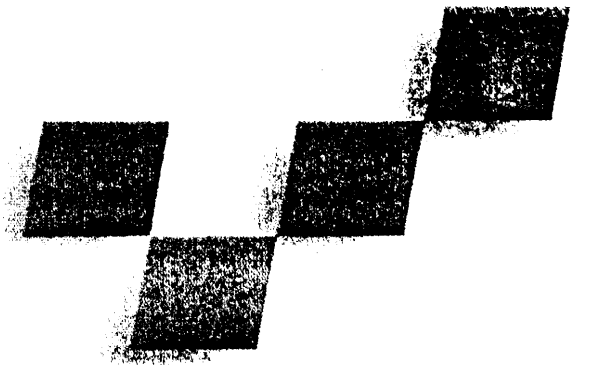

# Protecting Digital Image Copyrights: A Framework

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In the past decade, the scientific community has engaged in an intensive discussion of security issues for digital data. Piracy of such data has obstructed the rapid evolution of digital networks, digital libraries, and World Wide Web services. The convenient broadcasting or exposition of digital products on the global network leads easily to illegal copying and retransmission. The same happens with data transmitted through insecure channels.

Today, digital data security covers such topics as access control, authentication, and copyright protection for still images, audio, video, and multimedia products.' The networking environment of the future will require tools that provide

- secure and fast digital data encryption and decryption,
- content verification (authentication) of the received data by the recipient, and
- robust and trustworthy marks indicating copyright and legal ownership.

**Digital watermarks offer a way to counter copyright piracy on the global network. We summarize the fundamental concepts of watermarking and describe a general framework for a copyright protection system.**

For the first of these items, private- and public-key cryptography are widely used and have well-established algorithms. (These include RSA, the Rivest-Shamir-Adleman algorithm, and DES, the Data Encryption Standard?) For authentication, one proposal is digital signatures, which are also based on cryptographic algorithms? In this article, we address the third item. We describe how *digital watermarking* can contribute significantly to a realistic framework for protecting intellectual property rights in digital media.

## What is a digital watermark?

The concept of the digital watermark is a new topic[4,5] associated with the data-hiding technique known as steganography? Steganography, or "covered writing," has a long history that includes various methods of secret communication. In contrast to cryptography, steganography does not immediately arouse suspicion of something secret or valuable. Instead, it hides an important message within an unimportant one. Watermarking—also called tamper-proofing or content verification[7]—hides a secret and personal message to protect a product's copyright or to demonstrate its data integrity.

An important difference between steganography in general and watermarking relates to the attacker's goal. A pirate tries to reveal the information a steganography message carries. However, a pirate tries either to remove a watermark to violate a copyright or to cast the same watermark, after altering the data, to forge proof of authenticity.

Generally, the watermarking of still images, video, and audio demonstrate certain common fundamental concepts. Without significant loss of generality, we will focus on watermarking still images with a sufficient number of grayscale levels or colors (8-bit grayscale or 24-bit color images). Using such images as examples, we discuss the efficiency of watermarks for copyright protection.

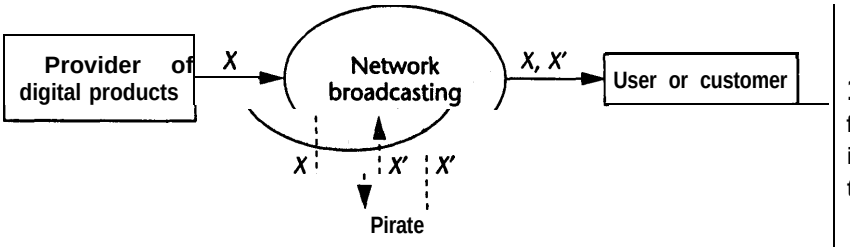
## Digital image protection via watermarking

To understand the role of watermarks in an intellectual property (IP) protection framework, consider the elementary digital media delivery system presented in Figure 1. The user gets a digital product from a provider-the copyright owner or an authorized distributor. Access and transmission take place in a global network environment. Users who do not retransmit the products do not violate the copyright property. Pirates harm the copyright owner by reproducing and retransmitting digital products illegally. That is, pirates function as unauthorized providers.

A protection scheme should give providers a reliable method for efficiently searching the network for copies that originally belonged to them. Such a scheme should also supply strong indications for asserting legal ownership.

A digital watermark (called also a copyright label or

invisible stamp) is associated with a unique private identification number called a *watermark key*. Under a watermarking-based protection scheme, each provider possesses a unique secret key $K_{pr}$ (or a finite set of keys). The scheme itself consists of the following actions:[1,7]




**1 Basic system for digital image distribution.**

- The copyright owner alters the digital data of the original image $I_0$ to produce the watermarked image $I_w$ by using the private key and a public or private algorithm $\hat{E}$: $I_W = \hat{E}(I_0, K_{pr})$.
- The copyright owner can detect the watermark by using an algorithm $\hat{D}$:

$$\hat{D}(I,K) = \begin{cases} 1 \text{ if } I \sim I_w \text{ and } K = K_{pr} \\ 0 \text{ otherwise} \end{cases} \quad (1)$$

The relation $A \sim B$ denotes perceptual similarity between images A and B. $I_0 \sim I_w$ because watermarking should produce almost invisible alterations.

To complete the watermarking scheme, we include the following actions, which are optional on the part of the provider:

- The provider possesses a personal archive $L$ of original digital images and a matching procedure $\hat{m}$ such that

$$\hat{m}(I, L) = \begin{cases} 1 \text{ if } \tilde{I} \in L \text{ and } \tilde{I} \sim I \\ 0 \text{ otherwise} \end{cases} \quad (2)$$

- The provider registers watermark key $K_{pr}$ to a trusted authority and ensures its uniqueness.
- The provider registers watermarked images $I \in L$ with a trusted authority to establish (time-stamp) ownership of 1.

The aim of this copyright protection system is to enable providers to check possible violation of their copyright property by monitoring the traffic and exposition of digital images in the distribution network. Positive detection of the provider's watermark ($\hat{D}(I, K_{pr}) = 1$) is an indication of ownership that the provider can use as substantiated evidence in a court of law. The registration of the originals to a trusted authority can give full proof of ownership in case of detection ambiguities-for example, if there has been an attack on the watermark.

## Basic watermarking procedures

The literature contains various definitions of digital watermarks.[8–10] For digital images of size Nx $M$, it is convenient and quite general to consider 2D watermark signals that consist of binary or, more generally, ternary elements:

$$w = \{w(k): \mid w(k) \in \{-1, 0, 1\}, \mathbf{k} \in \hat{W}\}$$

or white noise in [-1, 1]. $\hat{W}$ denotes a 2D grid of size $N$ x M. Vector k indicates the grid positions of the watermark pixels.

The three fundamental stages of watermarking are generation, embedding, and detection. Figure 2 shows a schematic presentation of the overall algorithm.

### *Watermark generation*

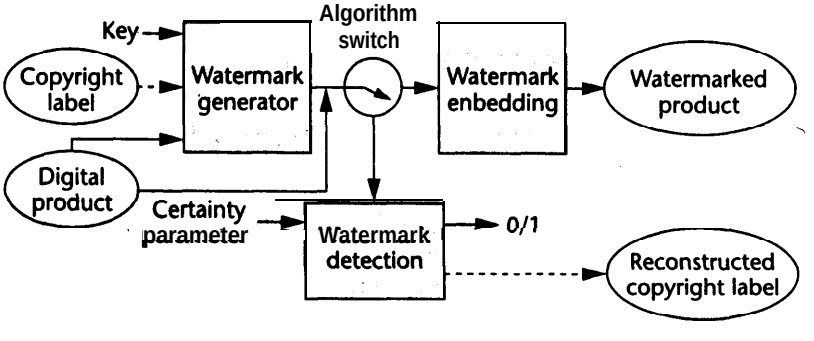
Let $\mathbf{W}$ be the set of possible watermark signals-that is, all the signals having elements in (-1, 0, 1}. We consider the finite and countable space K of keys. If X denotes the set of digital images, we define a watermark generation procedure by the noninvertible function

$$G: \mathbf{X} \times \mathbf{K} \to \mathbf{W}, W = G(I,K)$$

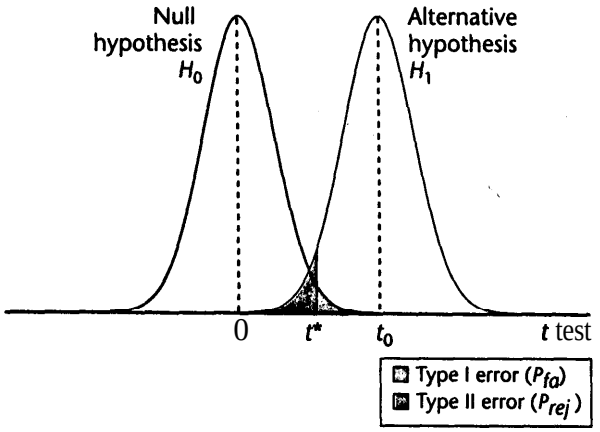
where $K \in$ K is the watermark key, and $I \in$ X is the image in which the watermark will be embedded. Without loss of generality, we decompose G as follows:

$$G = T \circ R, R: \mathbf{K} \to \mathbf{W}, T: \mathbf{W} \times \mathbf{X} \times \mathbf{K} \to \mathbf{W}$$

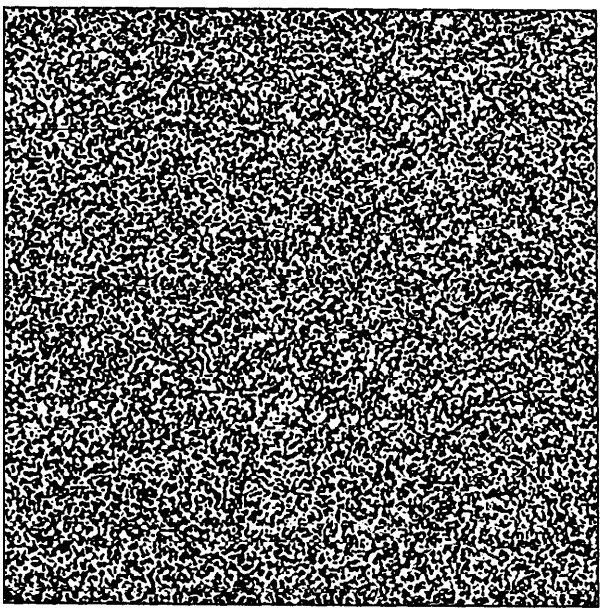
*R* should be noninvertible" and may be based on a pseudorandom-number generator or, generally, on chaotic systems. When we insert key $K$ in *R, we* create a fixed watermark $W_0 = R(K)$. *T* modifies $W_0$ to obtain the final watermark *W* that depends on the particular image. The watermark modification function *T* should take into account only robust characteristics of the image data. The original image $I_0$, the watermarked one $I_w$, and a modified copy of $I_w$ (denoted $I'_w$) must result




**2 Overall watermarking algorithm, including embedding and detection, both of which require watermark generation first. The copyright label is a binary stream that carries public information about ownership.**




**3 The distributions of the detector output for the null hypothesis (watermark does not exist) and the alternative hypothesis (watermark exists) for statistical detection , based on the $t$ test. Certainty ($c = 1 - P_{fa}$) depends on the selection of the $t$ threshold $t^*$.**



**4 A chaotic binary watermark for embedding in a digital image.**

adequately in the same watermark when perceptual similarity is satisfied:

$$w = T(W_0, I_0) \cong T(W_0, I_w) \cong T(W_0, I'_w)$$
$$\text{for any } I_0 \sim I_w \sim I'_w$$

### *Watermark embedding*

We define the embedding procedure as a superposition of the digital watermark signal $W = \{w(k)\}$ onto the original image $I_0 = \{x_0(\mathbf{k})\}$ of the same dimension. We denote the embedding procedure by $E$, which we define as

$$E: \mathbf{X} \times \mathbf{W} \times \mathbb{R}^2 \to \mathbf{X}, x_w(\mathbf{k}) = x_0(\mathbf{k}) \oplus H(\mathbf{k}) \otimes w(\mathbf{k}) \quad (3)$$

$H(k)$ is a 2D *watermark embedding mask* that controls watermark visibility and robustness. $\oplus$ is a superposition operator including appropriate truncations and quantization, and $\otimes$ is a generalized multiplication operator. The expression $I_w = \{x_w(\mathbf{k})\}$ denotes the watermarked image. The recovery of the original from the watermarked image is desirable but not necessary, because the copyright owner can store the original in a private archive. Instead of applying this embedding procedure directly to the intensity or luminance domain, we can apply it to the discrete cosine transform (DCT) **domain**[8,9] or the **wavelet domain.**[12]

### *Watermark detection*

Watermark detection is the most crucial part of a watermarking framework. By adopting a **hypothesis-testing** framework, in practice we obtain detection errors and deviate from the ideal detection (Equation 1). Such errors fall into two categories:

- *Type I errors.* We detect the watermark, but it does not actually exist in the data. Such false positives contribute to the probability of false alarm ($P_{fa}$) .
- *Type II errors.* We do not detect the watermark in the data, but it does exist. Thus, we get false negatives that contribute to the probability of false rejection ($P_{rej}$).

Taking these error probabilities into account, we define a detection procedure as follows:

$$D: \mathbf{X} \times \mathbf{K} \to (0, 1) \subset \mathbb{R}$$

$$D(I, W) = D(I, G(I, K_{pr})) = c$$

The output c denotes the certainty of a positive detection. The final decision is based on

$$c \geq c_{thres} \Rightarrow \text{watermark exists}$$

Generally, $c = f(t)$, where $t$ is a test statistic. The parameter $c_{thres}$ is the certainty level for detection, chosen by the image provider who applies detection. It is associated with a test value $t^*$ that controls (balances) the two error types. Figure 3 illustrates this situation. When c is close to unity, false negatives become insignificant ($P_{fa} \to 0$). However, at the same time, $P_{rej}$ increases and, consequently, the detector's overall performance declines. $D$ approaches the ideal detector $\hat{D}$ (see Equation 1) when both $P_{fa}$ and $P_{rej}$ tend to zero.

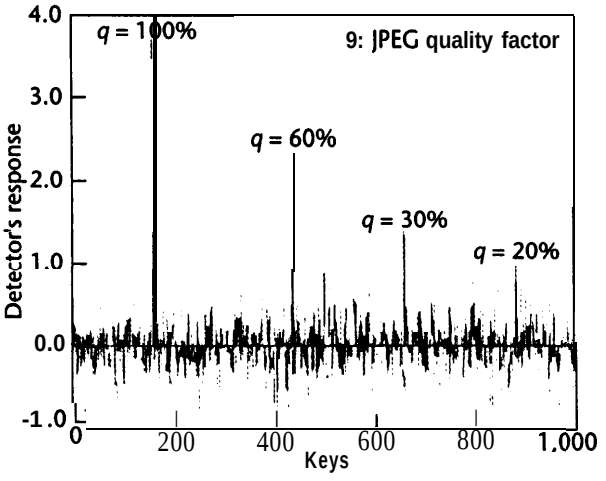
This detection scheme performs a binary decision with a given certainty level and answers the fundamental question, "Does watermark $W(I, K_{pr})$ exist in product I?" In the framework we propose, only the legal owner, who possesses key $K_{pr}$, can perform detection. Therefore, in principle, it is redundant to hide **multibit** information identifying the owner in the watermarked product. However, bitstream information hiding and retrieval (possibly **error-corrected**[13]) can increase certainty in the detection process or give illustrative indications of ownership (such as a company logo) or store product manipulation operations. It would also be useful to embed ownership information for other reasons-for example, if a trusted authority watermarks the products of various owners with the same key.

### A watermarking example

Several already proposed watermarking schemes would work with the general framework we describe; we have presented such a scheme previously.[14] For the purposes of illustration, we summarize a simple version of the method and apply it to an image.

(a) (b)

**5 Embedding a digital watermark. (a) The original image, "Lenna." (b) Invisible watermarking of "Lenna" using $h = 2$ on the left section and $h = 8$ on the right section. The watermarking on the right section degrades the image.**




*6* **Watermark detector output for various incorrect keys (red peaks) and correct keys (blue peaks). With the correct keys, the system easily distinguishes the watermark in the original watermarked Image and high-quality compressed versions of it.**

Step A. The bivalued watermark $W_0 = \{w(i,j)\}$, presented in Figure 4 as a black-and-white image, is created by watermark generation procedure G using a chaotic system. The set of integer numbers is the watermarking key set. Each integer corresponds to a set of parameters for the chaotic system through a well-defined function. Therefore, each key represents a unique initial condition of the chaotic sequence and can create a sufficiently different watermark for each different key.

Using chaotic systems, we can efficiently control the watermark's low-pass characteristics to achieve sufficient robustness under lossy compression or low-pass filtering.

Step B. Let $I_0 = \{x(i,j)\}$ denote the 8-bit luminance space of the original image (Figure 5a) to be watermarked. As we discussed earlier, we apply operator $T$ to $W_0$ to obtain an image-dependent watermark $W$. Tmust preserve $W$'s main features-in our example, its low-pass character. This is feasible if $T$ alternates (or doesn't alternate) the watermarkvalues by taking into account robust characteristics of the image regions indicated, for example, by vector t = p + r(K). Here, p denotes the particular watermark pixel examined, and r is a key-dependent vector.

Step C. We form the watermarked image $I_w$, which is the same size as the original, by applying equation 3 and using a constant-embedding mask ($h_{ij} = h = const$). The symbol $\oplus$ denotes the usual addition operator and the necessary truncations.

$$xx_w(i, j) = \begin{cases} 0 & \text{if } x(i, j) + hw(i, j) < 0 \\ 255 & \text{if } x(i, j) + hw(i, j) < 255 \\ x(i, j) + hw(i, j) & \text{otherwise} \end{cases}$$

The constant $h$ should be small to guarantee the invisibility of the watermark in $I_w$. For $h = 2$ the result is the watermarked image presented in the left part of Figure 5b. When we use $h = 8$, as in the right part of Figure 5b, the watermark embedding causes clearly visible degradations.

Step D. We can apply detection to any image I of the same size. We generate watermark $W$ using the specific key and the image I. The image pixels are divided into two subsets A = $\{(i,j) | w_{ij} = 1\}$ and B = $\{(i,j) | w_{ij} = -1\}$, which have mean luminance values $\bar{A}$ and $\bar{B}$. We consider the following detection response:

$$R = D(I, W) = \bar{A} - \bar{B}$$

We assume that x and w are statistically independent random variables. Thus, $R$ should follow the normal distribution $N(\bar{R}, o)$, where $\bar{R} = 2h$ when $W$ exists in I and $\bar{R} = 0$ otherwise. When a watermarked image $I_w$ is modified somehow (for example, by lossy compression or filtering), we expect $R < 2h$. We assume the watermark exists when $R > R_{thres}$. The constant $R_{thres}$ is a threshold value associated with a certainty level $c_{thres}$ for a positive detection. After numerical experiments, we found that for $R_{thres} > 0.1$, the minimum detection certainty is 99.9 percent.

Figure 6 shows the detection response $R$ obtained from $I_w$ by using 1,000 incorrect watermark keys. The blue peaks of $R$ come from $I_w$ or versions of it that we JPEG-compressed for various JPEG (Joint Photographic Experts Group) quality factors. We used the correct key for each of these peaks. With a decreased $R_{thres}$, the system can detect the watermark even with high compression ratios (or, generally, major modifications). However, this would cause false alarms as well.

### Basic watermarking demands

The basic watermarking methods we have presented efficiently protect the copyright property if the following features characterize the elementary procedures G, E, and D.

### *Perceptual quality preservation*

Embedding a watermark in a digital image, video, or audio signal should not reduce its perceived quality. An nvisible watermark satisfies this requirement. Therefore, we should take human visual perception into ıccount when casting watermarks. In the embedding cheme described by Equation 3, the proper choice of he embedding mask $H(\mathbf{k})$ guarantees invisibility. That s, $|H(\mathbf{k})| <$ JND, where JND denotes just-noticeable listortion of the image. Some watermarking schemes ıave used human visual models that provide strong but nvisible image alterations.[15,16]

Generally, however, watermark invisibility implies ɔotential watermark removal by lossy compression, and, ɔossibly, by other processing operations. Small per-:eivable alterations that cannot be considered distor-ions of the original, or that do not reveal artifacts under ɔostprocessing operations (if necessary), offer a possi-ɔle alternative. We stress that, in most cases, only the watermarked image is available to the user.

### *Trustworthy detection*

We can evaluate the performance of a watermark detection procedure $D$ by using the total error probability $P_{err} = P_{fa} + P_{rej}$. The contribution of the errors $P_{fa}$ and $P_{rej}$ to form the total detection error $P_{err}$ is controlled by certainty level $c_{thres}$. We distinguish the following cases:

- Detection *with low* certainty. False alarms are frequent. However, the probability of missing the detection of a watermarked image is very small. Providers can ascertain the reliability of a positive detection by searching their archive for the image and applying the matching process $\hat{m}$.
- Defection *with high certainty* In this case, $P_{fa} \rightarrow 0$, and the detector provides very reliable positive detection. Watermark detection with extremely small false-alarm probability may stand by itself as sufficiently reliable evidence for proving legal ownership in a court of law. However, the rejection probability may become quite significant.

The capability of G to produce an enormous watermark set W consisting of obviously distinguishable elements in the detection procedure is a necessary condition for achieving very low false-alarm probabilities. Therefore, rich complexity should characterize watermark signals (for example, see Figure 4).

### *Computational efficiency*

Watermark casting and detection are two separate algorithms. They should be easy to use, applicable to any digital image, and trustworthy..Although the provider embeds watermarks in each product only once, detection should apply to a large set of publicly exposed images. Therefore, very fast watermark detection is desirable. The private key and the watermarked image should suffice to perform watermark detection. Watermarks can be combined with an automated search procedure that searches for illegal copies in any public network or broadcasting environment (web-crawling or monitoring).

A necessary condition for develoninn such a system is to avoid the use of the original product (or any information associated with it) in the detection algorithm. Otherwise, the network monitor would have to apply matching procedure $\hat{m}$ (Equation 2) between all network images examined and all images in the private archive. This would result in unacceptable computational complexity and make watermarking entirely useless. In our approach, watermarking is essentially a copyright signaling mechanism.

### *Robustness to digital processing*

Watermark robustness under image modification is an essential issue for copyright protection.[8,9] Any provider or user can modify an original digital image to improve quality, compress data, edit digitally, and so on. Protecting copyright while maintaining sufficient quality under these conditions is desirable. Preservation of image quality implies preservation of perceptual similarity. Usually, we demand watermarks to be robust under the following image-processing operations:

- *Lossy compression.* It is the most widely used procedure for storing and transmitting digital still images, video, and audio. The widely used JPEG and MPEG (Moving Pictures Experts Group) algorithms provide a high compression ratio and the desired quality. However, compression algorithms tend to remove invisible information that can be related to the watermark. Therefore, watermarks should combine invisibility and robustness simultaneously.
- *Filtering and enhancement.* Users apply filtering to remove noise or to improve the perceptual quality. This process can remove watermarks as well. In addition, attackers may develop filters specifically designed for watermark removal. Denoising filters are usually low-pass; thus, watermarks should possess low-pass characteristics.
- *Geometric modifications* In the case of digital images such modifications include scaling, rotation, cropping, reflection, line and column extraction or insertion, and combinations of these. Salient image features or the invariant properties of the Fourier domain have been used for casting robust watermarks? The watermark should cover the entire image so that it will be robust to cropping. Watermark detection in geometrically modified products without resorting to the original product is a difficult task. Although there has been considerable progress in this area recently, the problem is still unsolved in its general form."
- *Different* image presentations. A user or pirate can print a watermarked digital image and then create a new digital copy by rescanning. If this process does not reduce the image quality significantly, the watermark should still be detectable in the rescanned image.
- *Color correction.* Usually, watermarks are embedded in the luminance component so that they are resistant to compression. Therefore, they are resistant to color corrections.

## Intentional attacks on watermarks

The watermarking scheme we have described may be attacked directly or indirectly to undermine its capaci-

ty to indicate legal ownership. [18,19] The following sections discuss possible attacks and methods of defense against them. Remember, our scheme does not allow the use of originals in the detection procedure.

### *Extraction of counterfeit watermarks*

Pirates know the principle of the public watermarking detection algorithm. Thus, they may form a signal $W'$ for a particular image $I$, which forces the detector to indicate that the image is watermarked? In other words, W is a watermark signal never embedded in I, but the pirate uses it as his or her own watermark. However, W should be associated with a key $K \in$ K through the watermark generation procedure G. Because this procedure is generally not invertible, such an attack is extremely unlikely to succeed. Procedure $R$ usually inherits G's noninvertibility. Qiao and Nahrstedt describe a noninvertible scheme based on the DES cryptosystem.[11]

### *Detection of false positives*

A pirate, after a trial-and-error procedure, might find a key $K'$ that provides a positive detector response and then claim that $K'$ indicates his or her ownership. However, the pirate can find such a key only after approximately $1/P_{fa}$ applications of $D$, where $P_{fa}$ is the minimum acceptable false-alarm'probability. Watermark detection with relatively significant $P_{fa}$ becomes quite reliable when providers register their keys with a trusted authority. In such a case, the probability that the counterfeit key $K'$ coincides with a provider's registered key is extremely small.

### ***Statistical watermark*** *extraction*

A great number of digital images, all watermarked with the same key, must not reveal the watermark when the pirate applies statistical methods such as averaging. Therefore, watermarks should not be statistically recoverable. An efficient protection against such an attack is to use image-dependent watermarks.[20] We have anticipated this requirement by introducing procedure $T$ during watermark generation.

### *Multiple watermarking*

Multiple watermarking can be useful when product resellers want to embed their own watermark in a product.[9,10] However, an attacker may use this property to embed his or her own watermark. Both the original and the pirate's watermarks can be detected using the corresponding unique key. Generally speaking, we can detect the watermark embedded at a later stage with greater certainty. However, in general, we cannot definitely conclude which watermark was embedded first. In this case, the image's original owner is the only one who can produce a copy containing only his own watermark. Subsequently, the original owner can prove legal ownership in cases of conflict. This eventuality explains the need for a private archive and watermarked product registration, as described earlier.

### *Watermarking with arbitrary keys*

Malevolent users or pirates may apply watermarks to any accessible image by using arbitrary keys-a process known as "watermark bombing." If these products are publicly exposed, great confusion may arise during the automated watermark-searching procedure. The negative consequences of such an indirect attack are restricted by the fact that we demand an enormous set of watermark keys. An efficient method of preventing such an attack is to consider distribution restrictions on provider keys. Each watermarking software package should supplyjust one or a few keys to each provider for watermark casting.

### *Private key loss or* ***theft***

The loss of the private key can enable a pirate to remove the watermarks from all the images that belong to that particular owner. This would make the system dangerously unstable. A solution to this serious problem could be provided by a combination of secure time-stamping[2] and time-dependent watermarks. These actions would restrict such an attack to a small number of products. This solution has the drawback of increased detection complexity.

### *Miscellaneous modifications*

A pirate can apply a sequence of various uncommon image-processing operations to confuse the monitoring software or to desynchronize the detector. (For example, the pirate might use the "mosaic attack," which is essentially a cropping attack.[13]) Unfortunately, once the data are out in the distribution network, there is always the risk of watermark removal by new techniques. In this case, the sole protection is the registration procedure.

## Product registration

The use of Web servers or trusted third parties in a copyright protection system is one proposal for solving the problems that exist in a pure watermarking technique[11]. Product registration to a trusted authority is a well-established way of protecting intellectual property rights of various products-for example, books, software packages, and so on. Registration information can offer indisputable proof of original ownership and legal rights. A protection system based on product registration requires the following actions before product disposition:

1. The provider registers with a trusted authority, which provides a watermarking key (or set of keys) or, generally, a private watermark-embedding software package.
2. The provider uses the registered key or the private software to cast watermarks.
3. The provider includes the original product in an archive and registers the watermarked product with a trusted authority.
4. The provider conducts an automated watermark search on the distribution network. A provider whc uses low-certainty detection reinforces the reliability of a positive detection result by searching the archive.
5. Producing the registered copy in a court of law con stitutes proof of copyright ownership.

As this scenario shows, the inclusion of registratior

chemes in the protection system means that the watermark contribution is restricted to the monitoring and liscovery of illegally distributed products. The watermarking detector should provide a reliable detection :ertainty level, recommending that the provider pro-:eed with or decline further investigation by searching he archive. Afterwards, the registration authority must ›rovide the final and reliable proof of legal ownership.

## Conclusions

Watermarks efficiently protect copyright when basic iemands can be satisfied. However, the demand for watermarks to remain robust under digital image-pro-:essing operations has not yet been fully satisfied. Robustness to geometrical distortions is an essential remaining problem for schemes that do not use the original images in the detection procedure. Furthermore, new water-marking schemes must take into account optimizations of current processing algorithms and the development of new algorithms. Better future compression techniques, for example, must not destroy watermarks embedded at any earlier time.

A watermarking scheme should also be resistant to intentional attacks. Pirates will try to violate the protection system either by creating forged proofs of ownership or by undermining the capacity of the watermarking scheme to indicate legal ownership. We believe that a general scheme for effectively protecting digital products can be based on a combination of watermarking, the use of private archives, and product registration with trusted registration authorities. ■

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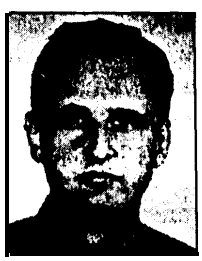


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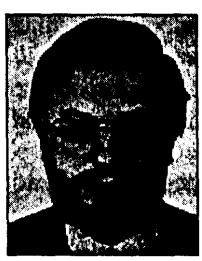


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